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Wind energy as a potential generation source at Ras Benas, Egypt

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ABSTRACT

Analysis of the wind characteristics in Ras Benas city located on the east coast of Red Sea in Egypt using measured data (wind, pressure and temperature) and Weibull function were made.

Statistical analysis model to evaluate the wind energy potential was introduced. According to the power calculations done for the site, the annual mean wind density is 315 kW/m^2 at a height of 70 m above ground level. This station has a huge wind energy potential for electricity generation, especially during spring and summer seasons, comparing with some European countries.

In addition, the monthly wind turbine efficiency parameter ($\eta_{monthly}$) has been calculated by using a commercial wind turbine 1 MW with 70 m hub height to help designers and users in evaluating the potentialities and choosing the suitable wind turbine for the considered site. The use of wind turbine with capacity greater than 1000 kW at this station was recommended.

Ras Benas station was selected to install 30 MW-wind farm consists of 20 commercial wind turbines (Nordex S 77) with hub heights and Rotor diameter were 100 and 77 m, respectively. This site has annual wind speed more than 9.8 m/s at 100 m height and enough area to locate these turbines.

The estimated energy production using WASP Program of these wind farm was 130 GWh/year. Furthermore, the production costs was found 1.3€ cent/kWh, which is a competition price at the wind energy world market.

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1. Introduction

Today, wind energy is widely used to produce electricity in many countries such as Denmark, Spain, Germany, United States, and India. Total wind power installed in Europe that is equivalent to 69% of the worldwide energy generated capacity, is 40 GW at the end of 2005. It is expected that the installed capacity in Europe will have reached 70 GW by the end of 2010 [1].

Electrical energy in Egypt is mainly produced by fossil fuels (oil and natural gas) and hydropower. Because of abundant energy resources, Egypt is heavily dependent on exported oil and gas [2]. Currently, Egypt produces electricity using wind farms at Zafarana, Gulf of El-Zayt and Abu Darag stations, which are located in the northern part along the Red Sea. Their electricity production presented to the country and due to an increase of needs Egypt exported these electricity to Jordan [3].

In our previous article [4], the authors made a technical assessment of wind power for 7 different sites located from north to south along the Red Sea in Egypt. Ras Benas station was one of

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the most promising sites. Mean speeds were 5.5 m/s at 10 m height and 8.90 m/s at 70 m height. This paper investigates the wind energy characteristics and wind turbine characteristics needed for the installation of wind energy conversion systems at Ras Benas, which is located in southern part along the coast of Red Sea. Moreover, the applications of wind turbines for electricity generation, in addition to a cost analysis of the utilized wind turbines are also investigated.

2. Description of wind data measurements

In this study, wind speed data measured as hourly time-series in meteorological station at Ras Benas city, were statistically analyzed. Fig. 1 shows the location of chosen site (35°30′N; 23°58′E) in southern region along the east coast of Red Sea in Egypt. These wind data at 10 m above ground level related to the selected site were taken from the Egyptian Meteorological Authority, for a period of more than 10 years. The measurements of monthly wind speed are presented in Table 1.

At Ras Benas station the wind blows from north 360°N (wind direction), i.e. the wind in Ras Benas are predominantly northerly [4]. This strongly preferred direction, however, is not only due to the general pressure gradient from north to south, but also caused by channeling of the wind flow between the mountain ranges that border the Red Sea zone in Egypt on both sides-reaching heights of 1000 m or more above sea level.

Also, the measured percentage frequency of winds blowing from all directions and the calm winds are shown in Table 1. This table indicates that:

(1) The mean wind speed during September 6.4 m/s has the highest frequency occurrence during the year (51.8%), followed by (44.3%) for mean wind speed 7.1 m/s at June, followed by (40.6%) at 6.3 m/s during May.
(2) So, during these months peaks of mean wind speed occur at different days with an average value of 6.3–7.1 m/s which is above the cut-in values required for the operation of any wind turbine in Egypt.
(3) Since the minimum required wind speed for a wind park (at 20 m height) is about 3 m/s which is equivalent to 2.54 m/s at 10 m height, atypical turbine will operate about 75–80% of all the time throughout the year [5].

The wind usually blows at varying speeds as a result of a change in the isobaric values of atmospheric pressure. It is clear from Fig. 2 that:

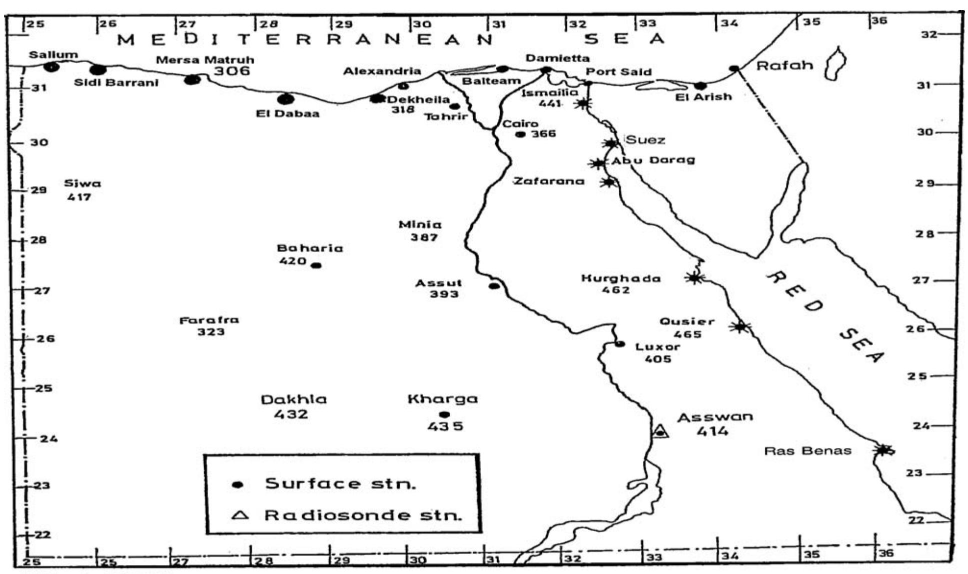

Fig. 1. Location of Ras Benas station along Red Sea in Egypt.

Table 1
Mean monthly of wind speed and its percentage frequency distributions (at a height 10 m).

Month	Mean wind speed	Percentage frequency of winds blowing from the following directions											
		345–14°	15–44°	45–74°	75–104°	105–134°	135–164°	165–194°	195–224°	225–254°	255–284°	285–314°	315–344°	Calm
January	4.8	24.9	6.6	2.3	1.7	1.4	1.7	1.0	0.2	0.4	2.5	12.4	33.9	11.0
February	4.8	28.2	8.0	2.7	2.0	2.4	3.0	1.0	0.3	0.1	0.9	8.4	33.4	9.6
March	5.4	30.6	6.4	3.0	2.7	2.9	3.1	1.2	0.2	0.2	2.0	7.3	28.3	12.1
April	5.6	34.9	6.4	2.6	2.7	3.3	6.2	1.7	0.3	0.3	1.1	4.6	25.8	10.1
May	6.3	40.6	6.1	2.0	1.2	1.8	2.6	1.0	0.2	0.1	0.6	5.8	27.3	10.7
June	7.1	44.3	4.1	0.8	0.7	0.6	0.7	0.3	0.1	0.1	0.3	5.9	31.9	10.2
July	5.3	32.7	9.7	3.3	1.8	1.4	1.1	0.8	0.2	0.1	0.3	6.0	21.2	21.4
August	5.5	31.9	11.8	3.7	1.6	0.6	0.2	0.2	0.0	0.2	0.7	5.8	21.5	21.8
September	6.4	51.8	5.0	0.4	0.3	0.2	0.1	0.0	0.0	0.1	0.4	4.1	27.9	9.7
October	4.8	35.4	6.8	1.5	1.8	1.5	1.7	0.5	0.1	0.1	0.6	7.3	30.8	11.9
November	5.1	32.6	6.5	1.9	2.2	1.5	0.6	0.2	0.0	0.1	0.5	10.9	33.2	9.8
December	4.7	28.0	5.3	1.4	1.4	1.9	0.9	0.4	0.0	0.2	1.3	11.4	37.9	9.9
Annual mean	5.5	34.7	6.9	2.1	1.7	1.6	1.8	0.7	0.1	0.2	0.9	7.5	29.4	12.4

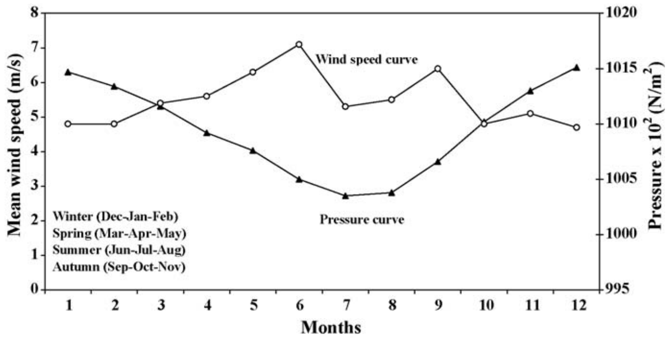

Fig. 2. Monthly variation of the wind speed and air pressure depending on measured data at Ras Benas station.

(1) The spring and summer seasons in Ras Benas is characterized by a marked increase in the mean wind speeds as a result of a decease in the isobaric values of atmospheric pressure.
(2) However, the noticed decrease in the mean wind speeds at winter and autumn seasons correlated to the increasing of pressure values observed.
(3) The highest average monthly wind speed was recorded at June 7.1 m/s (summer season) and the lowest was during December 4.7 m/s (winter season).
(4) The wind speeds which lie between 4.7 m/s (in winter period) and 7.1 m/s (in summer period) corresponding to an atmospheric pressure between 1015.1 and 1005.0 mb.
(5) The graph also shown that the peaks of wind speeds are correlated to the reduced values of pressure at different seasons or months throughout the year.

In addition, for evaluating the variation of the wind speed with elevation for this site, the mean speeds values were calculated using the power law [6,7], both monthly and annually for the heights of 70 and 100 m in the wind observation station. Obtained results are presented in Table 2. Annual mean wind speed at the 100 m height is determined as 9.8 m/s while the maximum mean wind speed was 12.6 m/s at June.

3. Statistical analysis model

In order to evaluate the wind energy potential of any site, it is important to drive the expected probability distribution of the site's wind speed. Regarding this aspect much attention has been given to the Weibull function, which gives a good match with experimental data according to Darwish and Sayigh [8]. The Weibull distribution is characterized by two parameters: the dimensionless shape parameter, k; and the scale parameter c which has units similar to the speed (m/s). The probability density function for density for the wind velocity V is calculated by [9,10]:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)^{k}\right] \quad (1)$$

where c and k are given by Justs et al. [11,12] as follows:

$$k = 0.83\,V^{0.5} \quad (2)$$

$$c = \frac{V}{\Gamma(1+k^{-1})} \quad (3)$$

where V is the mean wind velocity and Γ is the gamma function.

However, the available power of the wind per unit area is estimated by [13,14]:

$$P_{\text{wind}} = \frac{1}{2}\rho V_m^3 \ \ (\text{W/m}^2) \quad (4)$$

where ρ is the standard air density (ρ = 1.225 kg/m^3 dry air at 1 atm and 15 °C), V_m is the monthly mean wind speed (m/s).

In case of an ideal turbine, power output is influenced due to change in temperature and pressure. So, the corrected monthly air density $\bar{\rho}$ (kg/m^3) is expressed as [15,16]:

$$\bar{\rho} = \frac{\bar{P}}{R_d\bar{T}} \quad (5)$$

where $\bar{P}$ is the monthly mean air pressure (N/m^2), $\bar{T}$ is the monthly mean air temperature in degrees Kelvin (°C + 273) and, R_d is the specific gas constant for air (R_d = 287 J/kg ^{0}K).

Then the corrected power available in wind at the standard height 10 m, can be calculated as follows:

$$P_{10} = \frac{1}{2}\bar{\rho}V_m^3 \ \ (\text{W/m}^2) \quad (6)$$

In addition, for calculating the mean power density over a long time T for 1 month. If we take 30 days per month we end up with the following equation, where the available mean power for a height less than 100 m, above the ground level per month can be expressed as [17–19]:

$$P_{h(\text{mo.})} = \frac{720}{1000}\frac{1}{2}\bar{\rho}V_m^3\left(\frac{h}{10}\right)^{3\alpha} (\text{kW/m}^2\ \text{month}) \quad (7)$$

where α is the roughness factor, usually in the range $0.05 \le \alpha \le 0.5$. In this analysis, α = 0.25, is the standard value for the Egyptian terrain and wind conditions [20].

On the other hand, the turbine efficiency η, can be defined as the ratio between recoverable energy on the aerogenerator, E_R (kWh/m^2/year), and available energy at Betz limit, E_A (kWh/m^2/year). Last expression outlined in Refs. [21–24]. A simple estimating procedure can be introduced to estimate the monthly wind turbine efficiency by the following formula:

$$\eta_{\text{monthly}} = \frac{720}{S_a}\frac{P_r}{P_{h(\text{mo.})}} \quad (8)$$

where P_r is the rated power of the used wind turbine (kW), S_a is the rotor swept area (m^2).

While, we calculate the "capacity factor C_f", that is the ratio between the actual yearly energy output, E_{out}, and the rated yearly energy, $E_r = 8760P_r$ (a reference quantity that often is used as a rating–datum of the machine). The capacity factor of a wind turbine can be expressed [25,26]:

$$C_f = \frac{E_{out}}{E_r} \quad (9)$$

Lastly, the present value of money method is used for estimating the cost of a kWh produced by the chosen wind energy conversion systems (WECS). To calculate the present value of costs

Table 2
Estimated monthly and annual mean wind speed (m/s) at 70 and 100 m heights above the ground level in this site.

Mean wind speed	Month												Annual mean
	January	February	March	April	May	June	July	August	September	October	November	December	
V_{70}	7.8	7.8	8.8	9.1	10.2	11.6	8.6	9	10.4	7.8	8.3	7.6	8.9
V_{100}	8.5	8.5	9.6	10.0	11.2	12.6	9.4	9.8	11.4	8.5	9.1	8.4	9.8

Table 3
Monthly long-term shape parameter, k, and scale parameter, c, at 10 m hub height.

Month	k	C (m/s)
January	1.82	5.4
February	1.82	5.4
March	1.93	6.1
April	1.96	6.3
May	2.08	7.1
June	2.21	8.0
July	1.91	6.0
August	1.95	6.2
September	2.10	7.2
October	1.82	5.4
November	1.87	5.8
December	1.80	5.3
Annual mean	1.95	6.2

Table 4
Seasonal long-term shape parameter, k, and scale parameter, c, for Ras Benas station.

Period	k	C
Winter	1.82	5.4
Spring	2.00	6.5
Summer	2.03	6.8
Autumn	1.93	6.1

(PVC) of electricity produced per year, the following expression (Eq. (10)), which is in agreement with other works [27–29], is applied as well:

$$\mathrm{PVC} = I + C_{omr}\left[\frac{1+i}{r-i}\right] \times \left[1 - \left(\frac{1+i}{1+r}\right)^t\right] - S\left(\frac{1+i}{1+r}\right)^t \qquad (10)$$

where I = the investment includes the turbine price plus its 20% for the civil work and other connections; C_{omr} = operation costs that include operation, repair cost, and maintenance are taken as 25% of the annual cost of the turbine (machine price/life time); S = scrap value taken as 10% of the original investment; i = inflation rate (12%); r = discount rate (15%); t = lifetime of the wind machine (20 years).

4. Monthly and seasonal Weibull parameters

Eqs. (2) and (3) were applied to obtain the monthly and seasonally values of Weibull parameters k and c with the height of 10 m above the ground level for Ras Benas station. The results are shown in Tables 3 and 4. When using these values for hub height, k may be assumed to be unaffected by height, and the scale parameter c may be estimated from the usual power law which generally holds up to a height of 100–150 m [30].

From Tables 3 and 4 we can derive the following:

(1) The range of k is between 1.80 and 2.21, where the shape parameters tend to be higher from May to September during the year.
(2) The highest c value is 8.0 m/s in June and the lowest is found 5.3 m/s in December.
(3) The long-term seasonal k and c values are highlighted in Table 4. In general, values of the scale parameter are low throughout both (winter–autumn) seasons and high during the spring and summer periods.
(4) For large values of k at spring and summer seasons, the majority of the wind speed data tend to fall around the mean wind speed and then the mean wind speed at these seasons are high ($\upsilon_{\mathrm{Spring}} = 5.8\,\mathrm{m/s}$ and $\upsilon_{\mathrm{Summer}} = 6.0\,\mathrm{m/s}$). Hence, the wind is sufficient during the *half* of the year at Ras Benas City for high power generation.

5. Potential power resource

Yasmin et al. [16] concluded that, 71% of the power is extracted from the wind by the ideal turbine. An actual wind turbine can not extract more than 59.3% of the power in the wind which shows that an ideal turbine is not worth mentioning. The remaining 11.7% of the ideal wind power is not extracted due to existing turbines. Perhaps, it is either inappropriate efficiency of the turbine which can not utilize the remaining 11.7% of the wind power, or the effect of pressure and temperature. We have chosen the second possibility, which shows that even in the case of an ideal turbine, power output is influenced due to change in temperature and pressure.

By applying the measured wind data for Ras Benas station (monthly average air temperature, mean monthly of air pressure) with Eqs. (4)–(7), the values of corrected monthly air density $\bar{\rho}$, corrected monthly wind power P_{10} at a height of 10 m and the monthly wind power available P_{70} at hub height 70 m during the year were calculated and listed in Table 5. The results of P_{70} lead to Fig. 3.

From these table and figure, we found that:

(1) The obtained values of corrected monthly air density that they are almost stable and the shift from the standard air density (ρ = 1.225 kg/m^3) is very small. This confirms the stability of the atmosphere at Ras Benas city throughout the year.
(2) The absolute maximum highest wind power, P_{70}, was recorded in June 637.68 kW/m^2 and the absolute minimum of P_{70}, was found to be 194.62 kW/m^2 in December.

Table 5
Monthly corrected air density, corrected and available wind power and monthly values of wind turbine efficiency η_{monthly}, beside the observed values of air temperature and pressure for Ras Benas station.

Month	T (°C)	P ($\times 10^2$ N/m^2)	$\bar{\rho}$ (kg/m^3)	P_{10} (W/m^2)	P_{70} (kW/m^2 month)	η
January	18.3	1014.7	1.21	66.91	207.32	1.51
February	19.3	1013.4	1.21	66.91	207.32	1.51
March	21.9	1011.6	1.20	94.48	292.75	1.07
April	25.0	1009.2	1.18	103.61	321.04	0.98
May	28.4	1007.6	1.16	145.03	449.38	0.70
June	31.6	1005.0	1.15	205.80	637.68	0.49
July	31.8	1003.5	1.15	85.60	265.23	1.18
August	32.1	1003.8	1.15	95.67	296.44	1.06
September	30.9	1006.6	1.15	150.73	467.04	0.67
October	27.0	1010.2	1.17	64.70	200.48	1.56
November	23.4	1013	1.19	78.93	244.57	1.28
December	19.7	1015.1	1.21	62.81	194.62	1.61
Annual	25.8	1009.5	1.18	101.77	315.32	0.99

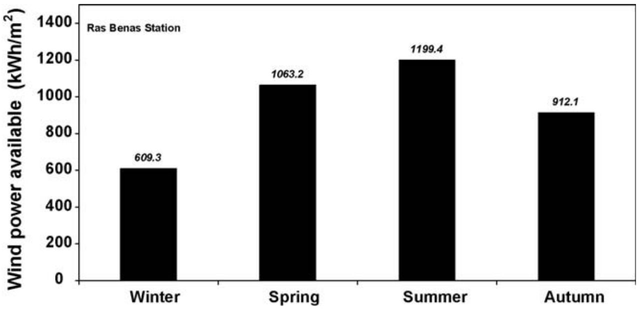

Fig. 3. Seasonal averages of available wind power during the year at 70 m hub height.

(3) In addition, in Fig. 3, the highest of value the mean power density for the summer season is 1199.35 kW/m^2 and then followed by 1063.17 kW/m^2 in spring for actual data. These confirm our results in Section 4. Hence, the power density available during the *half* of the year (spring–summer periods) at Ras Benas station is huge and suitable for high electricity generation. This information is similar to the power density in some European countries.

6. Wind turbine efficiency

The intent of the analysis presented – in this section of our research – is to help designers and users in evaluating the prospective potentialities of the considered site.

From the last sections and discussion the density of air is an important parameter which changes the efficiency of the wind turbine by about $\pm$10%. Keeping in view the efficiency of the wind machine at standard temperature and pressure, turbine efficiency can be increased by 10% in our estimated value of temperature and pressure.

Since the wind energy available in the wind cannot be completely extracted by any wind turbine, the wind turbine efficiency η, defined as the ratio of the recoverable energy on the aerogenerator outlet (rotor + gearbox + generator) is given by the machine power curve and the wind statistical distribution to the available energy by ideal wind turbine (at Betz limit) [21,25].

It can be seen from Eq. (8) that the wind turbine efficiency is not only a function of wind turbine performance, but also a function of wind speed distribution. The wind turbine efficiency enables us to figure out the relationship between energy available in the wind and how much energy a turbine can be transfer. It is important to note that the theoretical optimum for utilizing the power in the wind by reducing its speed was first discovered by Betz in 1926, as shown in many wind energy textbooks [31,32]. According to Betz, under the assumption that the turbine swirl and transmission losses were neglected, the theoretically maximum power that can be extracted from the wind is 59% of the wind power available in the wind. Therefore, for any wind turbine, the wind turbine efficiency η should not exceed 0.59.

For this study we used the commercial wind turbine "AN Bonus 1 MW/54" with swept area 2300 m^2 (main characteristics of this wind machine were presented at our paper [4]). By using the monthly values of mean wind speed for Ras Benas at a height of 70 m which are listed in Table 2 and then by substituting these values in Eq. (8), we obtain the monthly values of η at hub height 70 m for the last considered wind turbine 1000 kW, see Table 5 and Fig. 4.

From these table and figure, we can observe the following:

(1) The average annual of η for the wind turbine "*AN Bonus 1MW/54*" was found to be 0.99.
(2) The values of monthly wind turbine efficiency are greater than *0.59* for all months except at June during the year of Ras Benas station.
(3) Whereas the use of wind turbines with lower rated wind speeds will produce more energy in a year than wind turbines with higher rated speeds [26].
(4) So, we concluded that the use of a wind turbine which has a rated power *greater than* 1000 kW at 70 m at Ras Benas station is recommended.

7. Applications of electricity generation

The main objective of this study to evaluate the performance of 20 wind turbines operating in real conditions within a grid-connection wind farm with total capacity of 30 MW at Ras Benas station.

The amount of power generated by a wind turbine depends on both the design characteristics of the turbine and the properties of the wind resource represented by wind speed probability density. Matching the actual wind frequency distribution of the region with a suitable model of wind energy conversion system can maximize the energy output. This means, that in order to attain the maximum possible efficiency from a wind turbine it should be designed for that specific region. However, it is not practical to design a wind turbine for each location, because it is associated with extra funds. Therefore, usually a wind turbine – with parameters (such as cut-in speed, cut out speed, rated speed, and rated power), that best matches the wind characteristics of the region – is chosen from the existing wind turbines in the market [3].

So, the choice of the best suitable wind turbine for Ras Benas city is discussed. Whereas a technical and economic assessment of electricity generation from two turbine machines having capa-

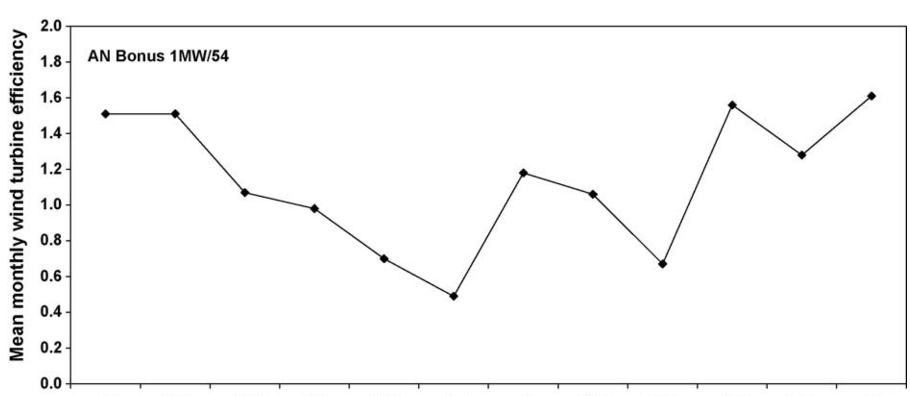

Fig. 4. Monthly variation of the mean wind turbine efficiency for a commercial wind turbine 1000 kW during the year at Ras Benas Station.

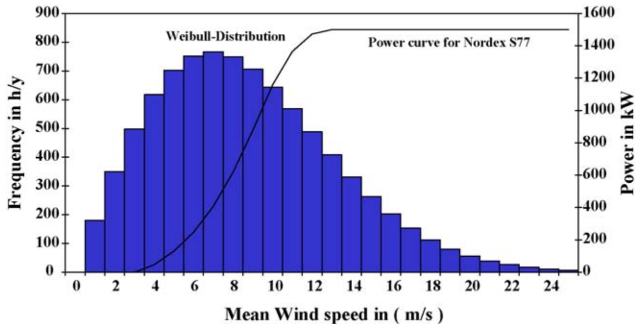

Fig. 5. Wind speed frequency distribution throughout the year in the site depending on estimated data by WASP program and the power curve for the 1500 kW selected wind machine.

cities of 600 and 1000 kW considered in seven different sites along Red Sea in Egypt (Ras Benas was one of them) was made in our article [4], and from the data presented and results in previous sections in this paper. From the results (Table 5 and Fig. 4) where the values of monthly wind turbine efficiency η – for considered wind turbine with capacity of 1000 kW "*AN Bonus 1MW/54*", and rated wind speed 15 m/s – are greater than *0.59* in 11 months during the year, the use of a wind turbine which has a rated power greater than 1000 kW at Ras Benas city is recommended.

Then, based on our results in article [26], it is concluded that the use of a wind turbine with lower rated speed will produce more energy over a year than a wind turbine with higher rated speed.

Hence, for this study the commercial wind turbine "Nordex S77" with a capacity of 1.5 MW and 100 m hub height was chosen, which has lower rated speed 13 m/s competitive with another commercial wind turbines of capacity 1500 kW in the market.

In this case, the annual assessment of energy production in one site is an important factor. Given the power curve of a specific wind turbine we are therefore able to estimate the actual energy production during the year by using WASP program [33,34], as shown in Fig. 5.

Turbines in the 30 MW-wind farm at Ras Benas station are considered to be located 150 m distance a part each other to prevent energy production loses of park effect. North was found as prevailing wind direction. Therefore, north seems the only wind direction to consider in wind farm project, which will developed on the campus area.

The technical data of the wind turbine "*Nordex S77*" used are summarized in Table 6. Using this data and the estimated annual mean wind speed at 100 m (hub height of this wind machine) will be 9.8 m/s at Ras Benas station together with the WASP program, the annual energy production, E_{out}, from the wind farm consists of 20 wind turbines with total capacity of 30 MW was found to be 130 GWh/year and the obtained capacity factor is high 49.5%, see Table 6.

Table 6
Annual energy gain and technical characteristics of wind turbine Nordex S77.

Turbine model	Nordex S77
E_{out} (kW/h/year)	6,507,012.0
Rated power (P_r)	1500 kW
Hub height	100 m
Rotor diameter	77 m
Swept area	4657 m^2
Number of blades	3
Cut-in wind speed (V_{ci})	4 m/s
Rated wind speed (V_r)	13 m/s
Cut-off wind speed (V_{co})	25 m/s
Price (€)	1,300,000

8. Economical evaluation

The present value of money method is used for estimating the cost of a kilowatt-hour produced by the wind farm with total capacity of 30 MW considered at Ras Benas station. We used Eq. (10) with followed assumptions, and in case of the wind farm, the capital investment, *I*, is taken as the number of units multiplied by the unit price, from which the PVC value was obtained [2]. Dividing this value by the total energy produced during the life time machines at wind farm, So, the expected cost of a kWh electricity generated is obtained as follows:

$$\mathrm{PVC} = 34,343,153$$

So, the specific cost per kWh = [(34,343,153)/(20 × 130,140,240)] = 1.3€ cent.

Hence, these results which contain the expected cost per kWh = 1.3€ cent, encourage the construction of several wind farms at Ras Benas city. Where the expected specific cost for electricity generation is a competition price at the wind energy world market.

9. Conclusions

In this research, establishment of wind farm with capacity of 30 MW to operate at Ras Benas station were studied. the results of this investigation were very promising. Observation of the measured and estimated values leads to the following conclusions:

(1) The wind in Ras Benas city is predominantly northly throughout the year. So, north seems the only wind direction to consider in wind farm project, which will be developed on the campus area.
(2) Annual mean wind speed for this site is ranging from 8.9 to 9.8 m/s at the heights of 70–100 m, which is similar to the strong wind speeds in some European countries.
(3) For the investigated station with Weibull parameters *k* and *c*, see Tables 3 and 4, we can drive that the wind is sufficient during the *half* of the year (spring and summer periods) for high power generation.
(4) The monthly corrected values of air density, see Table 5, is lightly smaller than the standard air density ρ = 1.225 kg/m^3. Which confirms the stability of the atmosphere at Ras Benas city during the year and therefore, it causes an improvement in the efficiency of wind turbines worked at this site.
(5) Investigation of available power density at the heights of 10–70 m indicates that, there are a huge wind power densities over the year, especially at *spring* and *summer seasons* in the range of 1063–1200 kW/m^2. This agrees with the information given by our Weibull parameters investigation.
(6) We recommend that at Ras Benas station, we should use wind turbines with rated power greater than 1000 kW at 70 m hub height.
(7) An estimation of cost analysis of installing a wind farm with total capacity of 30 MW (20 commercial wind turbines "*Nordex S77*" with a grid-connection) at Ras Benas station for electricity generation is carried out. The expected yearly energy gain from it was 130 GWh per year. Furthermore, the specific cost of each kWh was found to be 1.3€ cent, which is a competition price at the wind energy world market.

References

[1] Gökçek M, Bayülken A, Bekdemir Ş Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey. Renewable Energy 2007;32:1739–52.
[2] Ahmed Shata AS, Hanitsch R. Applications of electricity generation on the western coast of the Mediterranean Sea in Egypt. International Journal of Ambient Energy 2008;29(1):35–44.

[3] Hrayshat ES. Wind resource assessment of the Jordanian region. Renewable Energy 2007;32:1948–60.
[4] Ahmed Shata AS, Hanitsch R. The potential of electricity generation on the east coast of Red Sea in Egypt. Renewable Energy 2006;31:1597–615.
[5] Marafia A-H, Ashour HA. Economics of off-shore/on-shore wind energy systems in Qatar. Renewable Energy 2003;28:1953–63.
[6] Ilinca A, McCarthy E, Chaumel J-L, Rétiveau J-L. Wind potential assessment of Quebec Province. Renewable Energy 2003;28:1881–97.
[7] Kainkwa RMR. Wind speed pattern and the available wind power at Basotu, Tanzania. Renewable Energy 2000;21:289–95.
[8] Darwish ASK, Sayigh AAM. Wind energy potential in Iraq. Solar & Wind Technology 1988;5:215–22.
[9] Mathew S, Pandey KP, Anil Kumar V. Analysis of wind regimes for energy estimation. Renewable Energy 2002;25:381–99.
[10] Chang T-J, Tu Y-L. Evaluation of monthly capacity factor of WECS using chronological and probabilistic wind speed data: a case study of Taiwan. Renewable Energy 2007;32:1999–2010.
[11] Justus CG, Mikhail A. Height variation of wind speed and wind distributions statistics. Geophysical Research Letters 1976;3(5):261–4.
[12] Justus CG, Hargraves WR, Mikhail A, Graber D. Methods for estimating wind speed frequency distributions. Journal of Applied Meteorology 1978;17:350–3.
[13] Pimenta F, Kempton W, Garvine R. Combining meteorological stations and satellite data to evaluate the offshore wind power resource of Southeastern Brazil. Renewable Energy 2008;33:2375–87.
[14] Teetz HW, Harms TM, von Backström TW. Assessment of the wind power potential at SANAE IV base, Antarctica: a technical and economic feasibility study. Renewable Energy 2003;28:2037–61.
[15] Rehman S, Al-Abbadi NM. Wind shear coefficients and energy yield for Dhahran, Saudi Arabia. Renewable Energy 2007;32:738–49.
[16] Yasmin ZJ, Farooqui N, Durrani U, Raza SM. Wind resource potentials at Quetta. Solar & Wind Technology 1989;6(5):605–9.
[17] Ahmed Shata AS. Theoretical investigation and mathematical modelling of a wind energy system—case study for Mediterranean and Red Sea. Ph.D. thesis, submitted to Faculty of Electrical Engineering and Computer Science, Berlin University of Technology, Germany; June 2008.
[18] Khogali A, Albar OF, Yousif B. Wind and solar energy potential in Makkah (Saudi Arabia)—comparison with Red Sea coastal sites. Renewable Energy 1991;1(3):435–40.
[19] Awanou CN, Degbey JM, Ahlonsou E. Estimation of mean wind energy available in Benin (Ex Dahomey). Renewable Energy 1991;1(5/6):845–53.
[20] Ahmed Shata AS, Hanitsch R. Applications of electricity generation on the western coast of Mediterranean Sea in Egypt. In: 10th Portuguese–Spanish conference in electrical engineering (XCLEEE), Portugal, 2007.
[21] Ben Amar F, Elamouri M, Dhifaoui R. Energy assessment of the first wind farm section of Sidi Daoud, Tunisia. Renewable Energy 2008;33:2311–21.
[22] Pallabazzer R, Gabow AA. Wind generator potentiality in Somalia. Renewable Energy 1992;2(4/5):353–61.
[23] Mihelić-Bogdanić A, Budin R. Specific wind energy as a function of mean speed. Renewable Energy 1992;2(6):573–6.
[24] Johnson LG. Wind energy system. Englewood Cliffs, NJ: Prentice-Hall; 1985.
[25] Chang T-J, Wu Y-T, Hsu H-Y, Chu C-R, Liao C-M. Assessment of wind characteristics and wind turbine characteristics in Taiwan. Renewable Energy 2003;28:851–71.
[26] Ahmed Shata AS, Hanitsch R. Electricity generation and wind potential assessment at Hurghada, Egypt. Renewable Energy 2008;33:141–8.
[27] Habali SM, Hamdan MAS, Jubran BA, Adnan I, Zaid O. Assessment and applications of wind energy in Jordan. Solar Energy 1988;40(2):99–105.
[28] Sarkar M, Hussain M. The potential of wind electricity generation in Bangladesh. Renewable Energy 1991;1(5):855–7.
[29] Alnaser WE. Assessment of the possibility of using three types of wind turbine in Bahrain. Renewable Energy 1993;3(2/3):179–84.
[30] Gupta BK. Weibull parameters for annual and monthly wind speed distributions for five locations in India. Solar Energy 1986;37(6):469–71.
[31] Ackermann T, Söder L. An overview of wind energy-status 2002. Renewable and Sustainable Energy Reviews 2002;6:67–128.
[32] Patel MR. Wind and solar power systems. Florida, USA: CRC Press; 1999.
[33] Ozerdem B, Turkeli HM. Wind energy potential estimation and micro-sitting on Izmir Institute of Technology Campus, Turkey. Renewable Energy 2005;30:1623–33.
[34] Ngala GM, Alkali B, Aji MA. Viability of wind energy as a power generation source in Maiduguri, Borno state, Nigeria. Renewable Energy 2007;32:2242–6.